Name Date

HANDS-ON LAB

Exploring Newton's Laws

Engineers can take advantage of the relationships between net force, mass, and acceleration, which are expressed in Newton's laws of motion. Roped elevators, for example, take advantage of a massive elevator car, a single pulley, and the downward force of gravity on another hanging mass. The hanging mass, called a counterweight, is attached to a cable that loops over a special pulley called a sheave. The other end of the cable attaches to the elevator. The counterweight is approximately the same mass as the elevator when it is 40% occupied. Since about the same mass hangs from each side of the pulley, just nudging the system in one direction or the other can cause motion in the system. Once the elevator moves, little additional force is needed because the elevator will continue to rise due to the inertia of the falling counterweight, or to fall by its own inertia. An electrical engine provides the force needed to overcome or provide friction, which acts on the rope and provides a small additional force. It turns the sheave, which has grooves that pull on the cable. Since the engine must only "nudge" the system, not lift the entire weight of the elevator or counterweight, roped elevators are very efficient. They require little energy to operate.

In this lab, you will explore Newton's laws by investigating the relationships between inertia, net force, mass, and acceleration. In Part III, you will explore a system that is slightly modified from an elevator system. In your system, a counterweight will pull a cord attached to a cart that moves on a horizontal track. In the Extend activity, you will analyze a model elevator system called an *Atwood machine.* In both systems, the counterweight provides a constant force of gravity to one side of the system.

RESEARCH QUESTION What is the relationship between a cart's mass and its acceleration when experiencing a constant force?

MATERIALS

- safety goggles
- balance
- beaker
- books, to provide a barrier
- cardboard box, medium-sized
- coin, such as a quarter
- cord
- dynamics cart
- dynamics cart with spring mechanism
- human-figure toy or doll
- index card
- mass, 1 kg each (3)
- meterstick or measuring tape
- paper towels
- rubber band
- set of masses, 20 g–100 g
- stopwatch
- track with pulley and cart
- video camera (optional)
- water

MAKE A CLAIM

How does changing the mass of an object in a system affect the system's acceleration when a constant force is applied?

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SAFETY INFORMATION

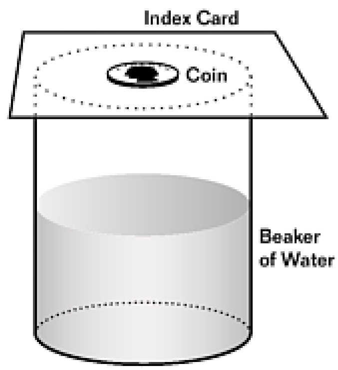
- Wear safety goggles during the setup, hands-on, and takedown segments of the activity.
- Perform this experiment in a clear area. Falling or dropped masses can cause serious injury.
- Tie back long hair, secure loose clothing, and remove loose jewelry to prevent their getting caught in moving or rotating parts.
- Wash your hands with soap and water immediately after completing this activity.

Name Date

PART I: AN OBJECT AT REST

CARRY OUT THE INVESTIGATION

1. Carefully fill the beaker about half-full with water. Wipe the lip and the outside of the beaker with a paper towel.
2. Place an index card on top of the beaker so that the card covers the opening of the beaker. Place the coin on top of the card.
3. Remove the index card by flicking it with your finger. Try to hit the edge of the card so it is pushed horizontally.



ANALYZE

1. What happened to the coin when the card was flicked out from underneath it?

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2. Is this what you expected to happen? Explain why or why not.

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3. What would happen to the coin if the card were pulled or pushed very slowly? Try it, and compare your results.

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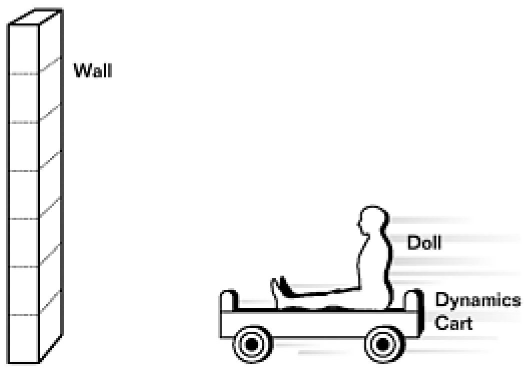
PART II: AN OBJECT IN MOTION

CARRY OUT THE INVESTIGATION

1. Choose a location where you can push a dynamics cart so that it rolls for a distance without hitting any obstacles or obstructing traffic and then hits a wall or other hard surface.
2. Place the toy or doll on the cart, and place the cart about 0.5 m away from the wall.
3. Push the cart and doll forward so that they run into the wall. Observe what happens to the doll when the cart hits the wall.
4. Place the cart at the same starting place, about 0.5 m away from the wall. Return the doll to the cart, and use a rubber band to hold the doll securely in the cart.
5. Push the cart and doll forward so that they run into the wall. Observe what happens to the doll when the cart hits the wall.
6. When you are finished, return the cart to the table or storage place. Do not leave the cart on the floor.



ANALYZE

1. What happened to the unsecured doll when the cart hit the wall?

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2. What happened to the doll secured with the rubber band when the cart hit the wall?

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3. How did the rubber band change the result of the experiment? Explain why this happened.

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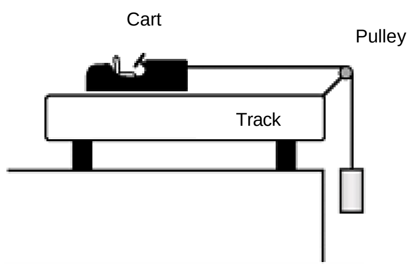
4. Compare the experiment with the doll and cart with the experiment with the card and coin. Explain how the results of the two are similar.

PART III: NEWTON'S SECOND LAW

CARRY OUT THE INVESTIGATION

1. Use an air track and cart or a dynamics track and cart to set up a system similar to the one shown below. When designing your system, make sure that the cart does not hit the pulley and falling mass does not roll away after hitting the floor. You may add other objects to your setup to act as safety features. Test your system before you continuing.



2. Describe a method to investigate how changing the mass of a system affects its acceleration. Consider the following as you develop your method:
   - Keeping the mass of the counterweight constant allows the net force acting on the system to remain constant.
   - The mass of your system is the mass of everything that is accelerating (cart + counterweight).
   - If your system starts from rest, the acceleration can be determined using the equation, $a = \frac{2\Delta y}{t^2}$, where Δy is the distance the counterweight falls in time t.
   - Unless your teacher tells you otherwise, do not exceed a mass of 300 g for the counterweight.

COLLECT DATA

1. What data will you collect and how will you organize your data? Keep in mind that when timing something that falls, doing multiple runs of the same trial is wise. Show what data you will collect by constructing a blank data table.

2. Show your procedure and data table with your teacher for approval before beginning your experiment.

ANALYZE

1. What caused the cart to start moving?

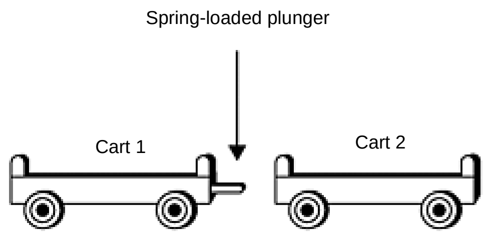
2. What relationship exists between the mass of the system and its acceleration?

3. Newton's big idea was that it is possible to determine the force acting on a system using only the system's mass and its acceleration. The force on your system is equal to the weight of the falling mass. Explain how you can determine this force from the system's mass and acceleration.

PART IV: NEWTON'S THIRD LAW

CARRY OUT THE INVESTIGATION

1. Set up two dynamics carts as shown. Choose a location where each cart will be able to move at least 1.0 m on a smooth horizontal surface away from obstacles and traffic. Compress the spring mechanism and place the carts so that they are touching.
2. Quickly release the spring, and observe the two carts. If you are working on a lab table, do not allow the carts to fall off the table.
3. Return the carts to their original positions, and compress the spring mechanism. Add a 1 kg mass to the cart with the spring.
4. Quickly release the spring, and observe the two carts.
5. Return the carts to their original positions, and compress the spring mechanism. Add another 1 kg mass to the cart with the spring. Release the spring, and observe the two carts.
6. Return the carts to their original positions, and compress the spring. Add a 1 kg mass to the second cart so that the mass on the first cart is twice the mass on the second cart. Release the spring, and observe the two carts.



ANALYZE

1. What happened to the two carts when the spring was released?

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2. Compare the motion of the carts for the different trials. Describe the motion in terms of the carts' acceleration from rest for each trial: carts with equal mass (no masses added), one cart with 1 kg mass added, one cart with 2 kg mass added, and one cart with 2 kg mass added and the other cart with 1 kg mass added.

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3. What is the relationship between the mass of a cart and its acceleration after the spring is released?

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Name **Date**

CONSTRUCT AN EXPLANATION

1. **Cause and Effect** Identify cause-and-effect relationships that you observed during any part of the lab. Explain how each cause-and-effect relationship might help you make a prediction about the motion of an object or group of objects.

2. **Use Computational Thinking** Newton's second law of motion may be stated as $F_{net} = ma$. Explain how this formula relates to what you observed during Part III of the lab.

DRAW CONCLUSIONS

Write a conclusion that addresses each of the points below.

Claim How does changing the mass of an object affect its acceleration? How does mass affect the acceleration of two objects acting on each other? Was your initial claim correct?

Evidence What evidence from each part of the investigation supports your claim?

Reasoning Explain how the evidence you provide supports your claim. Describe in detail the connections you make between the evidence you cited and the argument you are making.

EXTEND

Modify the system from Part III to make a model roped elevator. Attach a model elevator car (a cup into which you can add additional masses) to a cord that wraps around a pulley. Attach a counterweight (another mass) to the other end of the cord. This system is called an Atwood machine. What determines the rate of acceleration of this system? Collect evidence and reasoning to support your claim.